Laboratory modeling of density-gradient driven flows

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1. The free sinking of small solid spheres in a laboratory tank of finite size filled up with continously stratified fluid is characterized by a slowly decaying mode of oscillatory motion. The oscillations of spheres around the gravitational equilibrium level is generated by slowly decaying weak internal waves. These waves originate from the interaction of the spheres with the surrounding fluid. The strong initial damping during the first few periods does not quickly lead to a static gravitational equilibrium, weak oscillations survive for long periods. Gradual upward shift of the equilibrium level was also observed as a generic feature of the experimental setup. The empirical frequency of oscillations obtained by Fourier analysis are found to be very close to the local Brunt-Väisäla-frequency. The long term behavior of the spheres is an advection caused by the long lasting quasi-horizontal vortices. The temporal decay of oscillation amplitudes and velocities was found to follow a power-law. Its exponent is consistent with experimental results for decaying turbulence in a stratified fluid.

2. Internal gravity waves in the wake of a ship moving at the surface of two-layered fluid was investigated by the state of the art PIV method. The internal waves are strongly nonlinear, and a characteristic vortex-flow was newly detected, which is connected to the waves. Each vortex has a horizontal axis, and their centers are in the maxima and minima of the waves. The wave amplitudes and the vortex strength have the same resonant behavior as a function of the ship velocity. In homogeneous fluid neither internal waves nor the connected vortices were formed. The PIV measurements confirmed that the surface pressure distribution generated by the moving ship causes the presence of the internal waves and determines their geometry.

3. A nonlinear exchange flow over a thin sill was studied in a three-layered fluid in laboratory tank. Characteristic pulsation in the flow intensity

was visualized and measured in the vicinity of the sill. The oscillation frequency does not depend on the height of the sill at constant total fluid depth, but the amplitude and the average layer depth do change. Further tests showed that the key parameter determining the frequency is the total length of the tank. The frequency of pulsation was identified as the first eigenmode of surface seiche of the whole water body. Control experiments in a simplified setup unambiguously confirmed that initial configurations with horizontal pressure gradient always generate such oscillations. A thin sill at the pycnocline essentially translates the horizontal flow to vertical oscillations, which can be accurately measured. The results suggest practical methods for improved field observations.

4. Laboratory experiments are performed in an immiscible two-fluid system, where heterogeneous thermal convection is initiated by heating at the bottom and cooling at the top. The experiments were reproducible, the setup was chemically neutral and thermally stable, and the measurement technique was simply recording the time series of the bottom and top temperatures. A new dimensionless number was introduced, which is related to the density contrast and remained a very approximate parameter of the system. In the heterogenious convection the measured local temperature extremes did not coincide with the conspicuous dynamical events. This was because both fluids have strong thermal inhomogeneities, and intense internal convection proceeds together with the blob-exchange dynamics resulting in delays for the detected temperature signals on the upper boundary of the laboratory model. These temperature signals were analysed and compared to similar investigations of the Earth's mantle. Although the exact analogy with mantle convection due to the simple setup of the model fails, several details of convection driven turbulent systems (such as plumes, thermals) were explored.

5. Global statistics of daily mean temperature changes reveal a strong asymmetry. Warming steps have significantly higher frequency and lower average magnitude than those of cooling steps for most weather stations. This nonlinear feature and the obtained geographic distribution of asymmetry parameters suggested that the origin should be linked with the most essential determining factors of atmospheric dynamics: differential heating and rotation. Temperature measurements were performed in a classical rotating tank experiment in the dynamical regime of geostrophic turbulence. They quantitatively reproduce the asymmetry and spatial dependence of field observations.